# 4. Potential Indoor Air Quality Impacts of Burning Candles and Incense

## 4.A Candles

When candles are burned, they emit trace amounts of organic chemicals, including acetaldehyde, formaldehyde, acrolein, and naphthalene (Lau et al., 1997). However, the primary constituent of public health concern in candle emissions is lead. Metal was originally put in wicks to keep the wick standing straight when the surrounding wax begins to melt. The metal prevents the wick from falling over and extinguishing itself as soon as the wax fails to support it. The US candle manufacturing industry voluntarily agreed to cease production of lead-containing candles in 1974, once it was shown that burning lead-wick candles resulted in increased lead concentrations in indoor air (Sobel et al., 2000b). Unfortunately, despite the voluntary ban, lead wick candles can still be found on the market.

According to the National Candle Association (NCA), most US candle manufacturers have abided by the agreement to cease lead wick production. All of the NCA members have signed pledges not to use lead wicks in candles they manufacture. In addition, the NCA has sent a letter to all the candle manufacturers registered with the Thomas Register of American Manufacturers informing them of the potentially adverse health effects associated with wicks that contain lead and asking them to sign pledges not to use wicks containing lead in their candles. The NCA has also sent letters to retailer trade associations to inform them of this issue.

The NCA states that only a small number (one or two) of candle manufacturers make their own wicks.  The rest purchase wicks from wick manufacturers.  One such manufacturer is Atkins and Pearce, Inc.; they claim to have stopped making and selling wicks with lead in 1999.

The Candle Product Subcommittee of the American Society of Testing and Materials (ASTM) is working on voluntary standards for candle content, including labeling standards.  It is anticipated that this standard will address the lead issue.  The draft standard was presented at the fall 2000 ASTM meeting.

There have been limited investigations regarding the prevalence and source of candles with lead wicks.  ERG did not find any statistical studies investigating the presence of lead-wick candles in the US marketplace.  However, a handful of studies contain some information about the occurrence of lead-wick candles in the local study areas.  The following discussion and Table 6 present information on lead and other chemicals emitted from candles.

***Lead Wick Emissions***

In February 2000, the Public Citizen's Health Research Group conducted a study of the lead content of candles in the Baltimore-Washington area.  They purchased 285 candles from 12 stores, excluding candle-only stores, and tested the wicks for the presence of lead.  They found that nine candles, or 3% of the candles they purchased, contained lead.  Total lead content ranged from approximately 24,000 to 118,000 μg (33 to 85% of the weight of the metal in the candle wick).

An academic study was conducted on the emissions of lead and zinc from candles with metal-core wicks (Nriagu and Kim, 2000). For this study, the researchers purchased and tested candles (found in Michigan stores) that had metal-core wicks. Fourteen brands of candles manufactured in the US, Mexico, and China were found to contain lead. Emission rates from candles ranged from 0.52 to 327 μg-lead/hour, resulting in lead levels in air ranging from 0.02 to 13.1 μg/m$^3$. These concentrations are below the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit[4] (PEL) of 50 μg/m$^3$, but above the EPA outdoor ambient air quality standard[5] of 1.5 μg/m$^3$. It is important to note that, although the EPA standard was not developed for use for indoor air comparisons, it is used throughout this report as a conservative comparison value. OSHA's PEL values should also be interpreted with some caution for they are occupational standards not designed for the protection of the general public, children, or sensitive populations.

Another prominent study, van Alphen (1999), examined emissions and inhalation exposure-based risks for candles having lead wick cores. The mean emission rate was 770 μg-lead/hour, with a range of 450 to 1,130 μg-lead/hour. A candle burned for 3 hours at 1,000 μg-lead/hour in a 50 m$^3$ room with poor ventilation is estimated to yield a 24-hour lead concentration of 9.9 μg/m$^3$, and a peak concentration of 42.1 μg/m$^3$. OSHA's 50 μg/m$^3$ PEL is not approached in this

---

[4]PEL (Permissible Exposure Limit): These OSHA standards were designed to provide health protection for industry employees by regulating exposure to over 300 chemicals. PELs are an 8-hour time weighted average.
[5]EPA Outdoor Ambient Air Quality Standards: Required by the Clean Air Act, these standards were set for pollutants thought to harm public health and the environment, including the health of "sensitive" populations such as asthmatics, children, and the elderly.

study, but again, EPA's outdoor ambient air standard of 1.5 $\mu g/m^3$ is exceeded.

Sobel et al. (2000a) modeled lead emissions from candles containing lead wicks. After burning multiple candles in a contained room, 24-hour lead concentrations ranged from 15.2 to 54.0 $\mu g/m^3$. The candle containing the least amount of lead produced lead concentrations of 30.6 $\mu g/m^3$ in 3 hours. The maximum concentration of 54 $\mu g/m^3$ is above the PEL standard of 50 $\mu g/m^3$ and EPA's outdoor ambient air quality standard of 1.5 $\mu g/m^3$.

***Other Metals***

*Zinc*

After the ban on lead-containing wicks, candle companies began looking for alternatives that provided the desired characteristics of the lead wick without the harmful emissions. Many companies turned to braided wicks, which consist of three smaller wicks wound together to provide some stiffness. Zinc cores are also commonly used, since the metal provides the desired amount of stiffness, burns off readily with the rest of the wick, and does not have the same toxic effects as lead.

Zinc is an essential element for human health. However, inhaling large amounts of zinc (as zinc dust or fumes from smelting or welding) over a short period of time (acute exposure) can cause a disease called metal fume fever. Very little is known about the long-term effects of breathing zinc dust or fumes (Eco-USA.net, 2000).

Nriagu and Kim (2000) found the release of zinc from metal-core wicks to be 1.2 to 124 μg/hour, which is too low to be of health concern in indoor air. All nonferrous metals have traces of lead impurities; for zinc, the maximum lead content is 0.004% (Barker Co., 2000). The lead emissions from zinc wicks are below the detection level of most test methods (Barker Co., 2000), though one study found emission rates of 0.014 μg-lead/hour (Ungers and Associates, 2000).

*Tin*

Tin is also commonly used as a stiffener for candle wicks. It is considered to be nontoxic (Chemglobe, 2000). Tin has a maximum lead content of 0.08%, but, like zinc, lead emissions are below the detection limit when tin wicks are burned (Barker Co., 2000).

***Organics***

Several organic compounds have been detected in candle emissions. Three articles have focused specifically on this topic. Lau et al. (1997) measured levels of selected compounds in candle materials and modeled human exposure to a worst-case scenario of 30 candles burned for 3 hours in a 40 $m^3$ room with realistic air flow conditions. Schwind and Hosseinpour (1994) analyzed candle materials and the combustion process, and created a worst-case scenario of 30 candles burned for 4 hours in a 50 $m^3$ room with approximately 0.7 L/min air flow. Fine et al. (1999) also performed a series of emission tests on the combustion of paraffin and beeswax candles burned in an air chamber with a volume of approximately 0.64 $m^3$ and an air flow rate of 100 L/min. Results of the studies are presented below and in Table 6.

*Acetaldehyde*

Acetaldehyde levels for 30 candles burned in an enclosed room for 3 hours were modeled at 0.834 $\mu g/m^3$ (Lau et al., 1997); this is above the EPA's $10^{-6}$ excess cancer risk level[6] of 0.5 $\mu g/m^3$, but below the EPA inhalation reference concentration (RfC)[7] of 9 $\mu g/m^3$.

*Formaldehyde*

Formaldehyde levels were measured at 0.190 $\mu g/m^3$ (Lau et al., 1997) and 17 $\mu g/m^3$ (Schwind and Hosseinpour, 1994). Again, these measurements were above the EPA's $10^{-6}$ excess cancer risk level of 0.08 $\mu g/m^3$, but below the OSHA PEL maximum of 921.1 $\mu g/m^3$. Formaldehyde levels for both studies were far below OSHA's STEL[8] maximum of 2,456.1 $\mu g/m^3$.

*Acrolein*

Maximum concentrations of acrolein were measured at 0.073 $\mu g/m^3$ (Lau et al., 1997) and <1 $\mu g/m^3$ (Schwind and Hosseinpour, 1994). These levels are above the RfC of 0.02 $\mu g/m^3$ and

---

[6] $10^{-6}$ excess cancer risk level: This EPA comparison value is the air concentration known to produce an increased risk of 1 in 1,000,000 for cancer.

[7] RfC (Reference Concentration): This EPA health-based comparison value assumes that there is a threshold for certain toxic effects. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

[8] STEL (Short-Term Exposure Level): This OSHA standard was designed to limit maximum concentrations of exposure as averaged over any 15 minute period. This is an occupational standard, not designed for the protection of the general public, children, or sensitive populations.

below the PEL of 250 μg/m$^3$. A cigarette burned in a similar environment produces acrolein levels of 23 μg/m$^3$ (Lau et al., 1997).

*Polychlorodibenzo-p-dioxins/Polychlorodibenzofurans (PCDD/PCDF)*

Levels of PCDD/PCDF were measured at 0.038 pg I-TEQ/m$^3$ (Schwind and Hosseinpour, 1994). The TEQ is the toxic equivalency method used to evaluate dioxins. It represents the sum of the concentrations of the multiple dioxin congeners "adjusted" to account for the toxicity of each congener relative to the most toxic dioxin, 2,3,7,8-TCDD.

*Polyaromatic Hydrocarbons (PAHs)*

The amount of PAHs measured in candle emissions and soot differs between studies. Fine et al. (1999) found that no significant levels of PAHs were detected in the emissions from normal burning and smoldering candles. In contrast, Huynh et al. (1991) found that soot from wax-light church candles contained measurable concentrations of PAHs: the study measured 882 μg benzo[ghi]perylene per gram of candle soot and 163 μg benzo[a]pyrene per gram of candle soot. However, Huynh et al. did not measure PAH concentrations from candles in air. Wallace (2000) also concluded that a citronella candle was a source of PAHs in a study of real-time monitoring of PAHs in an occupied townhouse, but did not quantify the concentration or emission rate.

Concentrations of benzo[a]pyrene in air due to candle emissions can measure 0.002 μg/m$^3$ (Lau et al., 1997). This is below the PEL value of 200 μg/m$^3$. Naphthalene maximum concentration levels were measured at 0.04 $\mu g/m^3$ (Schwind and Hosseinpour, 1994), below the EPA RfC of 3 $\mu g/m^3$.

*Alkanes, Wax Esters, Alkanoic and Alkenoic Acids, Alkenes*

Fine et al. (1999) found that the majority of emissions from candles consisted of organic compounds including alkanes, wax esters, alkanoic and alkenoic acids, and alkenes. Some of the compounds found were thermally altered products of the unburned wax, while others were unaltered in the volatilization process. Concentrations of the organic compounds in air were not calculated.

***Particulate Matter***

The diameter of candle flame particles have been measured between 20 and 100 nm (Li and Hopke, 1993) and 100 and 800 nm depending on the mode of burning (Fine et al. 1999). Neither study calculated maximum concentrations of particles in air. Li and Hopke (1993) subjected candle flame particles to relative humidity comparable to that in the human respiratory tract, and found that candle flame particles grew in size. White candles had a 20% larger growth potential than scented candles.

**Table 6: Indoor Air Impacts of Burning Candles**

| Contaminant | Study | Maximum Concentration | STEL | PEL | RfC | $10^{-6}$ Excess Cancer Risk |
|---|---|---|---|---|---|---|
| Lead | Nriagu and Kim | 0.02- 13.1 µg/$m^3$ | NA | 50 µg/$m^3$ | NA | NA |
| | van Alphen | 42.1 µg/$m^3$ | | | | |
| | Sobel et al.(2000a) | 15.2 to 54.0 µg/$m^3$ | | | | |
| Zinc | Nriagu and Kim | 1.2-124 µg/hour [a] | NA | NA | NA | NA |
| Tin | NA | NA | NA | NA | NA | NA |
| Acetaldehyde | Lau et al. | 0.834 µg/$m^3$ | NA | 360,000 µg/$m^3$ | 9 µg/$m^3$ | 0.5 µg/$m^3$ |
| Formaldehyde | Lau et al. | 0.190 µg/$m^3$ | 2,456.1 µg/$m^3$ | 921.1 µg/$m^3$ | NA | 0.08 µg/$m^3$ |
| | Schwind and Hosseinpour | 17 µg/$m^3$ | | | | |
| Acrolein | Lau et al. | 0.073 µg/$m^3$ | NA | 250 µg/$m^3$ | 0.02 µg/$m^3$ | NA |
| | Schwind and Hosseinpour | <1 µg/$m^3$ | | | | |
| PCDD/PCDF | Schwind and Hosseinpour | 0.038 pg I-TEQ/$m^3$ | NA | NA | NA | NA |
| Benzo [*a*] pyrene | Lau et al. | 0.002 µg/$m^3$ | NA | 200[1] µg/$m^3$ | NA | NA |
| Naphthalene | Schwind and Hosseinpour | 0.04 µg/$m^3$ | NA | 50,000 µg/$m^3$ | 3 µg/$m^3$ | NA |
| Alkanes, Wax Esters, Alkanoic and Alkenoic Acids, Alkenes | NA | NA | NA | NA | NA | NA |
| Particulate | NA | NA | NA | NA | NA | NA |

[a]This number represents an emission rate, not a concentration. A maximum concentration was not calculated for zinc.

### *Candle Soot*

Black Soot Deposition (BSD) is also referred to as ghosting, carbon tracking, carbon tracing, and dirty house syndrome. Complaints of BSD have risen significantly since 1992 (Krause, 1999).

Black soot is the product of the incomplete combustion of carbon-containing fuels. Complete combustion would result in a blue flame, and would produce negligible amounts of soot and carbon monoxide. Until recently, the source for the black soot in homes was unknown. Through interviews and recent experiments, it is now believed that frequent candle burning is one of the sources of black soot. The amount of soot produced can vary greatly from candle to candle. One type of candle can produce as much as 100 times more soot than another type (Krause, 1999). For example, elemental carbon emission rates varied from <40 to 3,370 μg/g candle burned in a study of sooting behavior in candles (Fine et al., 1999). The type of soot may also vary; though primarily composed of elemental carbon, candle soot may include phthalates, lead, and volatiles such as benzene and toluene (Krause, 1999).

Scented candles are the major source of candle soot deposition. Most candle wax paraffins are saturated hydrocarbons that are solid at room temperature. Most fragrance oils are unsaturated hydrocarbons and are liquid at room temperature. The lower the carbon-to-hydrogen ratio, the less soot is produced by the flame. Therefore, waxes that have more fragrances in them produce more soot. In other words, candles labeled “super scented” and those that are soft to the touch are more likely to generate soot.

The situation in which a candle is burned can also impact its sooting potential. A small and stable flame has a lower emission rate than a larger flickering flame with visible black particle emissions (Vigil, 1998). A forced air flow around the flame can also cause sporadic sooting behavior (Fine et al., 1999). Thus, candles in glass containers produce more soot because the container causes unsteady air flow and disturbs the flame shape (Stephen et al., 2000). Candles that are extinguished by oxygen deprivation, or blowing out the candle, produce more soot than those extinguished by cutting off the tip of the wick. Cutting the wick eliminates the emissions produced by a smoldering candle (Stephen et al., 2000).

When soot builds up in air, it eventually deposits onto surfaces due to one of four factors. First, the particle may randomly collide with a surface. Second, soot particles can be circulated by passing through home air-conditioning filters. Third, soot can gain enough mass to become subject to gravity. Homes with BSD often have carpets stained from soot deposition (Vigil, 1998). Finally, the particles are attracted to electrically charged surfaces such as freezers, vertical plastic blinds, television sets, and computers (Krause, 1999).

When soot is airborne, it is subject to inhalation. The particles can potentially penetrate the deepest areas of the lungs, the lower respiratory tract and alveoli (Krause, 1999). ERG did not find research literature on the health effects of residential exposure to candle soot.

### *Conclusion*

Candles with lead wicks have the potential to generate indoor airborne lead concentrations of health concern. It is also possible for consumers to unknowingly purchase candles containing lead wick cores and repeatedly expose themselves to harmful amounts of lead through regular candle-burning.

Lead wicks aside, consumers are also exposed to concentrations of organic chemicals in candle emissions. The European Candle Association (1997) and Schwind and Hosseinpour (1994) conclude that there is no health hazard associated with candle burning even when a worst-case scenario of 30 candles burning for 4 hours in a 50 $m^3$ room is assumed. However, burning several candles exceeded the EPA's $10^{-6}$ increased risk for cancer for acetaldehyde and formaldehyde, and exceeded the RfC for acrolein. Once again, the RfC and EPA's $10^{-6}$ increased cancer risk guidelines are not designed specifically for indoor air quality issues, so these conclusions are subject to interpretation.

Consumers may also not be aware that the regular burning of candles may result in BSD, causing damage to their homes.  Sooting can be reduced by keeping candle wicks short, drafts to a minimum, and burning unscented candles.

Additional research may want to focus on gaps in the literature, such as emissions from scented and multi-colored candles, and maximum concentrations of organics in air produced by sooting candles.

### 4.B Incense

Several studies found associations between exposure to incense smoke and many illnesses, including cancer, asthma, and contact dermatitis.  Incense burning was found to be a contributing factor in the occurrence of asthma for Quatar children (Dawod and Hussain, 1995), and coughing was found to be associated with incense exposure in a study of Taiwanese children (Yang et al., 1997).  Burning incense produces volatile fragrances that, once airborne, can reach exposed skin, causing dermatitis (Roveri et al., 1998).  An elevated risk for leukemia was found in children whose parents burned incense during pregnancy or while nursing (Lowengart et al., 1987).  A study of childhood brain tumors showed elevated risk for children whose parents burned incense in the home (Preston-Martin et al., 1982).

From comparing mutagenic potencies of incense, formaldehyde, and acetaldehyde to *Salmonella typhimurium* T102, Chang et al. (1997) concluded that incense smoke contains highly active compounds with a higher mutagenic potency than formaldehyde. Sato et al. (1980) and Rasmussen (1987) have also found that incense smoke is mutagenic to *S. typhimurium* TA98, TA 100, and TA104. Incense Smoke Condensates (ISCs), the particles released during incense burning, were found to be mutagenic and/or genotoxic in the Ames test, the SOS chromotest, and the SCE/CHO assays. The genotoxicity of certain ISCs in mammalian cells was also found to be higher than particles produced from tobacco smoke condensates (TSCs) (Chen et al., 1990).

Interestingly, one study concluded that burning incense decreases the chances of developing lung cancer (Liu et al., 1993). However, this study was conducted in China, where societal factors may have influenced the results of the study. For example, people using incense may be more well off and therefore have healthier life styles in general (Liu et al., 1993). A few studies examined emissions of specific contaminants from incense smoke. These results are discussed below.

### *Carbon Monoxide*

Carbon monoxide inhibits the blood's ability to carry oxygen to body tissues including vital organs such as the heart and brain. Symptoms of carbon monoxide exposure vary widely based on exposure level, duration, and the general health and age of an individual. Typical symptoms include headache, dizziness, and nausea. These 'flu like' symptoms often result in a misdiagnosis and can cause delayed or misdirected treatment. Contact with high levels of carbon monoxide can result in unconsciousness and death (EPA, 2000b).

Although Löfroth et al. (1991) found that burning incense produced sizeable amounts of carbon monoxide (220 mg/g incense burned), the authors concluded that it is not likely to exceed EPA regulatory standards unless the incense is burned in a very small room with very little ventilation. The standard used for a comparison value in the study was the EPA's outdoor ambient air quality standard of 10 mg/$m^3$. This is not necessarily the most appropriate comparison value, especially since mg/g incense burned, not maximum indoor air concentration, was reported.

***Isoprene***

Isoprene is a hydrocarbon created and emitted from plants and trees during respiration, and has also been detected in tobacco smoke and automobile exhaust. Isoprene does have genotoxic properties (EDF, 2000).

Interestingly, the predominant exposure to isoprene comes from its formation in the human body. An exhaled breath contains 1-3 mg/$m^3$ of isoprene. Löfroth et al. (1991) concluded that 1.1 mg isoprene/g incense burned would not result in adverse health effects. Again, maximum indoor air concentrations were not provided in this study.

***Benzene***

Löfroth et al. (1991) compared benzene emissions from the food preparation process, cigarette smoking, and burning incense. The study found that emissions of benzene resulting from burning an incense cone were 440 μg/g incense burned. Löfroth et al. concluded that this emission level could possibly cause an increase in indoor benzene concentrations above urban air background levels of 2-20 μg/$m^3$. A maximum indoor benzene concentration was not calculated in this study, so we cannot justifiably compare Löfroth's value to the EPA $10^{-6}$ excess cancer risk estimates, reported as a range of 0.13 to 45 μg/$m^3$ (EPA, 2000a).

**Musk Xylene, Musk Ketone, and Musk Ambrette**

Musk xylene (2,4,6-trinitro-1,3-dimethyl-5-tertiary butyl benzene), musk ketone (3,5-dinitro-2,6-dimethly-4-tertiary butyl acetophenone), and musk ambrette (2-methoxy-3,5 dinitro-4-methyl-tertiary butylbenzene) are contained in some types of Chinese incense (Roveri et al., 1998). They are known for making skin more sensitive to light and causing irritations. When incense is burned, airborne particles may dissolve in the upper layer of skin and allergic contact dermatitis may arise. However, toxicity and health data for these chemicals are not available.

***Particulate Matter***

Burning incense was found to generate large quantities of particulate matter (Mannix et al., 1996). Mannix et al. estimated the median diameter of particulates in aerosols to be between 0.24 and 0.40 μm, and hypothesize that particles could deposit in the respiratory tract. Mannix et al. did not perform a chemical characterization of compounds present in the particulate phase, but recommend that a human exposure scenario be done. Li and Hopke (1993) also found that incense smoke produced larger particles, in the range of 0.1 to 0.7 μm. Tung et al. (1999) found that $PM_{10}$ concentrations in Hong Kong homes were 23% higher with smoking or incense burning– the mean indoor $PM_{10}$ level for all homes was 78.8 $\mu g/m^3$, while mean $PM_{10}$ for smoking or incense-burning homes was 96.6 $\mu g/m^3$. This is below the EPA's national ambient air quality 24-hour standard of 150 $\mu g/m^3$, but above the annual standard of 50 $\mu g/m^3$. Chao et al. (1998) found that burning incense in a home with poor ventilation could result in a peak concentration of total suspended particulates (TSPs) of 1,850 $\mu g/m^3$. In 1987, EPA began using $PM_{10}$, particles measuring 10 $\mu m$ or less in diameter, rather than TSPs as the standard unit of measure. However, before that time, the standard for outdoor TSPs in the United States was 260 $\mu g/m^3$ for a 24-hour average and 75 $\mu g/m^3$ for an annual average. The concentration of particulates found in Chao et al. (1998) far exceeds 260 $\mu g/m^3$.

***Polyaromatic Hydrocarbons (PAHs)***

Reports of PAHs in incense soot have been contradictory. Chang et al. (1997) did not find PAHs in the vapor extract of incense smoke. However, Koo (1994) determined that PAH levels rose with incense burning in a study of Hong Kong residences. Incense soot was found to contain measurable concentrations of fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[def,p]chrysene, benzo[ghi]perylene, ideno[1,2,3,-cd]pyrene, anthanthrene, and coronene (Huynh et al., 1991). Though the study established that the maximum dust concentration corresponded with the burning of incense, maximum concentrations of PAHs from incense burning were not calculated.

## *Conclusion*

Incense produces particulate matter that can deposit in the respiratory tract, and elevates airborne concentrations of carbon monoxide and benzene. Incense also contains trace amounts of chemicals suspected of causing skin irritation, and exposure to incense has been linked with several illnesses. Incense smoke should be considered a source of indoor pollutants in rooms in which incense is regularly burned (Cheng and Bechtold, 1995). However, the studies reviewed measured emissions for only a limited number of incense types and brands; with the large range of incense manufacturers and importers on the market, other incense types could differ in the parameters examined.